Forests and forest soils: an essential contribution to agricultural production and global food security

Forests and forest soils play a broad, complex and interactive role within the environment

Soils have provided the foundation for trees and entire forests over millions of years. Soil is an important component of forest and woodland ecosystems as it helps regulate important ecosystem processes, such as nutrient uptake, decomposition, and water availability. Soils provide trees with anchorage, water and nutrients. In turn, trees as well as other plants and vegetation, are an important factor in the creation of new soil as leaves and other vegetation rot and decompose.

However, the relationship between soils and forests is much more complex and far-ranging. Soils and forests are intrinsically linked, with huge impacts on each other and on the wider environment. The interactions between forests and forest soils help to maintain the environmental conditions needed for agricultural production. These positive effects are far reaching and ultimately help to ensure a productive food system, improved rural livelihoods and a healthy environment in the face of change.

Forests, forest soils and their interactions carry out key functions that contribute to food security and a healthy environment

1. Climate change: what forests and forest soils do

Carbon emissions are a major contributor to climate change. The world´s forests, in one of their many roles, act as a significant carbon store. 650 billion tonnes of carbon, or nearly one third of the total in terrestrial ecosystems, are captured in forests. Forest soils also store a quantity of carbon equalling that of the global forest biomass, about 45 percent each. An additional ten percent of carbon is found in forest dead wood and litter.

2. Sustainable soil management needs sustainable forest management

The planet needs sustainably managed forests to control soil erosion and to conserve soil.

Tree roots stabilize ridge, hill and mountain slopes and provide the soil with the necessary mechanical structural support to prevent shallow movements of land mass: landslides rarely occur in areas with high forest cover.

Sound forest management practices, including measures to introduce or maintain forest cover on erosion-prone soils and run-off pathways, help control or reduce the risk of soil erosion and shallow landslides.

3. Major ecosystem benefits of forests and soils: clean water and watershed management

By reducing soil erosion and the risk of landslides, sustainably managed forests contribute significantly to the systems providing and maintaining the planet's supplies of clean water, while also ensuring a balanced water cycle.

Forests are also a key component of watershed management – an integrated approach of using natural resources in a geographical area drained by a water course. Watershed management is a very sound way to protect and rehabilitate areas prone to soil degradation and erosion in upland areas. Forest and soil characteristics are among the key parameters assessed in watershed management planning. Moreover, measures to restore and enhance soil fertility, e.g. through reforestation, have many benefits and are therefore an integral part of any watershed management plan.

4. Soil conservation in semi-arid and arid areas starts with forests and trees

Related links

FAO Forestry Department

In arid or semi-arid ecosystems, forests send 90 percent of rainfall back into the atmosphere. But by helping to prevent soil erosion, they act as a crucial protector of soil resources, for example in preventing or reducing salinization. The challenge in arid-zone forests is therefore to optimize the trade-offs, between water yield and soil protection.

5. Forests can reduce mountain soils' sensitivity to degradation

Steep slopes and thin soil make mountain ecosystems extremely vulnerable to erosion. Mountain soils are often degraded and invariably do not provide enough nutrients for plants to grow well. FAO estimates that around 45 percent of the world's mountain area is not or only marginally suitable for growing crops, raising livestock or carrying out forestry activities. The degradation of mountain soil and vegetation cover may happen gradually or rapidly but often takes many years to repair; in some cases it is irreversible.

The challenges that mountain farmers must overcome are many: short vegetation periods, steep slopes, shallow soils and the occurrence of landslides. To survive, they have had to develop different ways of averting or spreading risks, employing complex and diversified farming systems on croplands, pastures and forests. They know that they must make use of different soil types at different altitudes and at different times of the year.

In order to protect our soils, we need to protect our trees and forests

The importance of these effects has often been ignored in the past, with the clearance of tree vegetation and the subsequent loss of millions of hectares of productive land. Furthermore, as forests continue to be cleared-exposing the land to direct attack from wind and rain-soil erosion and land degradation are still undermining agriculture's resource base. In order to protect our soils, we need to protect our trees and forests. Both of these vital resources play pivotal roles in food security and a healthy environment.

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International Year of Soils 2015
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DIGGING DEEPER How Much Do Roots Contribute to Slope Stability?

Keen observers have long recognized that trees help stabilize soils on steep mountain slopes. Lyell (1853) and Marsh (1864) interpreted associations between forest cutting and mass wasting as evidence that forest clearing accelerated erosion in mountainous terrain. Since Lyell's day, the influence of root reinforcement on shallow landsliding has been well established by studies of landslide erosion under mature forest and in harvested plots, mechanistic studies of root reinforcement, and theoretical analyses based on the infinite-slope stability equation (eq. 5.8), where root strength is considered as part of the cohesion term (Sidle et al., 1985). Although roots contribute to soil strength by providing apparent cohesion and holding the soil mass together, they have a negligible effect on frictional strength. Studies from the western United States, Japan, and New Zealand all indicate that the stability of the soil mantle on steep, soil-mantled slopes depends in part on reinforcement by tree roots and that after the loss of forest cover (either by timber harvest or fire), the decay of tree roots increases the potential for slope instability, especially when soils are partly or completely saturated (Sidle et al., 1985; Bierman et al., 2005).

Root reinforcement may occur through the base of a potential landslide as roots grow into the underlying bedrock or more stable surface materials. Dense, interwoven root networks both reinforce soil and provide lateral reinforcement across potential failure scarps. Burroughs and Thomas (1977) demonstrated a rapid decline in the tensile strength of Douglas-fir roots following timber harvest in western Oregon and central Idaho and indicated the increased potential for landslides when trees were removed. Building on the Burroughs and Thomas approach, Sidle (1992) developed a quantitative model of root-strength reinforcement that combined the decay of roots after timber harvest with the regrowth of new roots [**Figure DD5.1**]. Although the decay and regrowth times vary for different tree species, a period of low root strength occurs some time between 3 and 20 years following timber harvest or fire. If a big storm occurs in

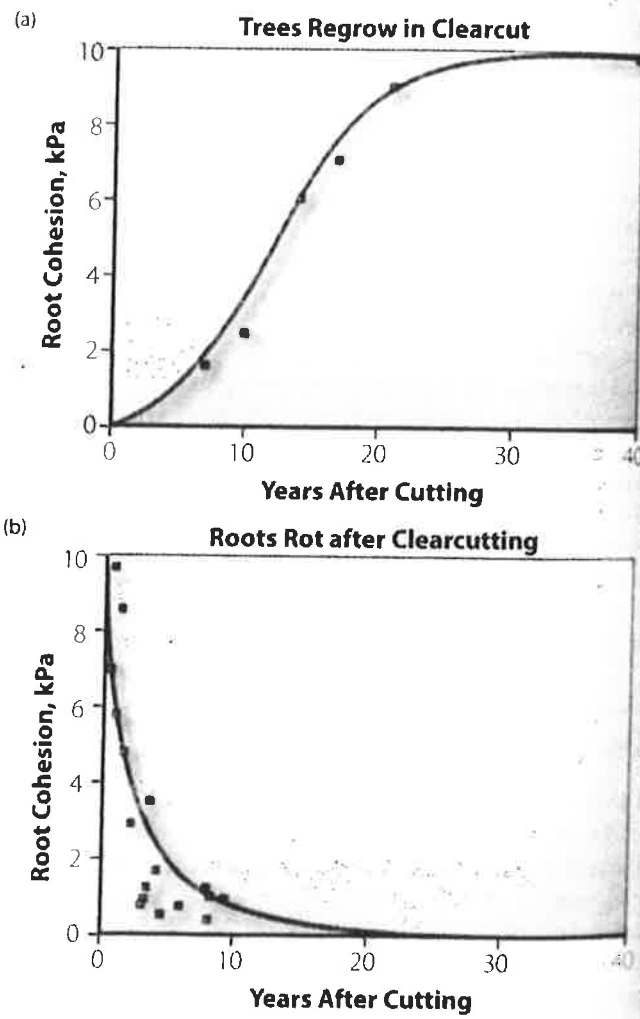

FIGURE DD5.1 Root strength changes over time as (a) trees grow in clearcuts and (b) as roots decay after trees are clear-cut. It takes about a decade after cutting for the dead roots of coastal Douglas fir trees to lose all of their strength and about 20 years for new trees to take root and develop full root strength. Planting seedlings right after harvest is a land-management strategy that reduces the chance of landsliding because new roots are growing as the old ones are decaying. [From Sidle (1992).]

6a. Attachment F

this window and saturates the soil, landslides will likely follow.

Studies comparing the rate of landsliding on forested versus clear-cut slopes have reported a range of effects, from no detectable increase in landslide frequency to more than a ten-fold increase following timber harvest (Sidle et al., 1985). In a study that both analyzed a regional data set of 3200 landslides and intensively monitored a study area, Montgomery et al. (2000) found that storms with 24-hour rainfall recurrence intervals of less than 4 years (common storms) triggered landslides in the decade after timber harvesting in the Oregon Coast Range [**Figure DD5.2**]. Comparison of these postharvest rates of landsliding with the estimated background rate implied that clear-cutting of slopes increased landsliding rates by 3 to 9 times over the natural background. This increase reflected reduced root strength as the dead roots of the cut trees rotted and weakened. Without strong roots, less soil saturation was required to induce slope failure, and thus smaller storms could trigger landslides.

Schmidt et al. (2001) measured root cohesion in soil pits and scarps of landslides triggered during large storms in February and November of 1996 in the Oregon Coast Range. They found a preponderance of broken roots in the margins of recent landslide scarps, indicating that root tensile strength contributed to stabilizing the soil (until the roots snapped) in most locations. They also found that root density, root penetration depth, and the tensile strength varied among species; the tensile strength increased nonlinearly with root diameter. The median lateral cohesion provided by roots in mature natural forest ranged from 26 to 94 kPa. It was much lower in planted, industrial forest stands, ranging from 7 to 23 kPa. In clear-cuts, the lateral root reinforcement was uniformly low, under 10 kPa [**Figure DD5.3**].

Similar to Montgomery et al. (2000), Schmidt et al. (2001) found that a persistent reduction in root strength

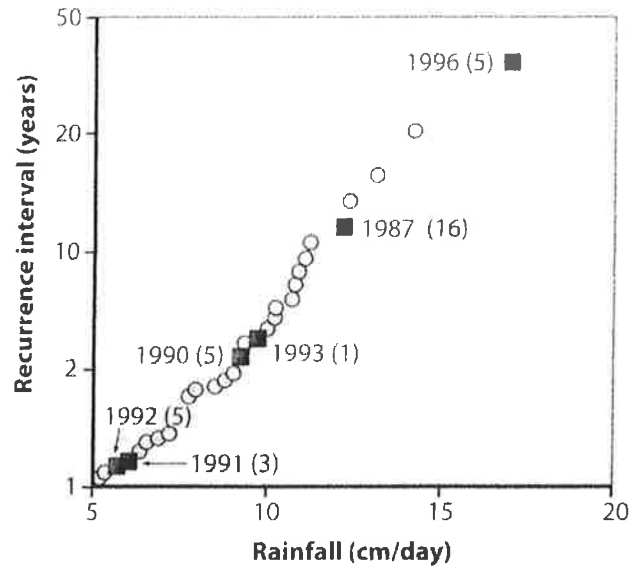

FIGURE DD5.2 Plot of recurrence intervals for 24-hour rainfall events from 1931 through 1996 (yellow circles) in a steep 0.43 km^2 study area that was clear-cut in the 1980s. Storms that occurred after clear-cutting and are known to have generated landslides are shown as blue squares. Numbers in parentheses after years indicate how many landslides occurred. Note that eight landslides occurred in this area during storms having less than 2-year recurrence intervals, all after clear-cutting. Vertical axis is logarithmic. [From Montgomery et al. (2000).]

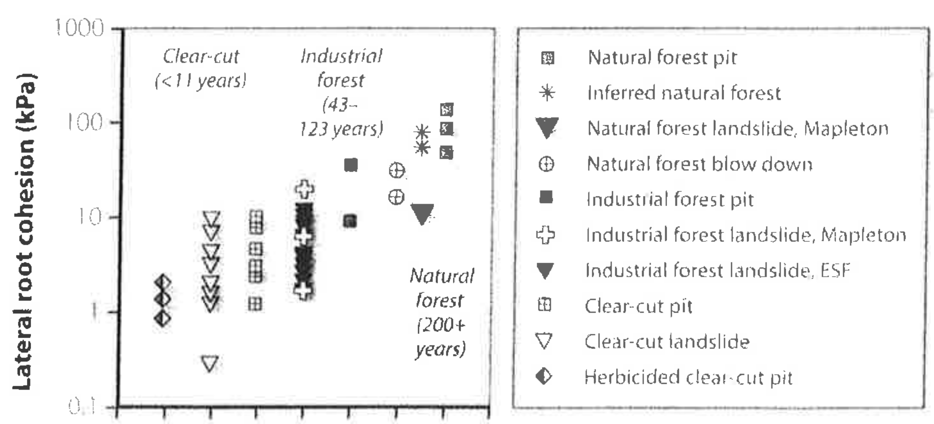

FIGURE DD5.3 In the Oregon Coast Range, not all roots provide the same amount of lateral root cohesion. Roots in clear-cuts do little to stabilize slopes. Industrial forests, those planted and managed for wood products, have roots that provide some stabilization, but the highest apparent root-cohesion values are found in mature, natural forests. [From Schmidt et al. (2001).]

DIGGING DEEPER How Much Do Roots Contribute to Slope Stability? *(continued)*

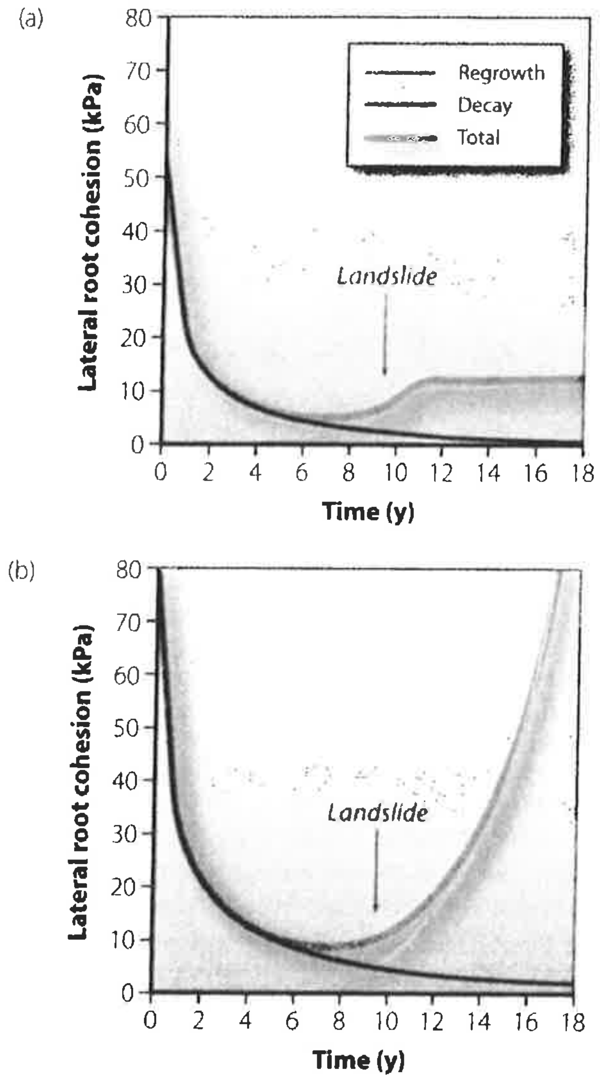

FIGURE DD5.4 Predicted total lateral root cohesion considering contributions from tree regrowth and decay of old roots for two sites that were clear-cut in 1986 and yielded landslides in 1996. Figure (a) represents a site where understory regrowth dominates vegetation. Figure (b) is a site where growth consists of abundant conifers and deciduous trees. [From Schmidt et al. (2001).]

resulting from timber harvest significantly reduced the soil moisture (m in eq. 5.8) required to trigger slope instability. They modeled root decay and regrowth for two sites that were clear-cut in 1986, and then slid in 1996. Both failures occurred close to the predicted root-strength minima, about 10 years after clear-cutting [**Figure DD5.4**].

Root strength varies spatially in a forest, complicating slope-stability modeling. Roering et al. (2003) documented the distribution and characteristics of trees adjacent to 32 shallow landslides in the Oregon Coast Range. Not surprisingly, bigger trees had larger root systems. The diameter of the tree crown and the root network was a function of the tree diameter (and thus tree age), and Roering et al. (2003) quantified root strength in landslide scarps by pulling on roots and measuring the tensile strength at which they broke. Summing the total root strength in each landslide perimeter, they found that root strength correlated with the size, species, condition, and spacing of trees around the landslide scarps; bigger, healthier trees spaced more closely together gave greater root strength. They also found that landslides tended to occur in areas of low root strength and thus that the potential for shallow slope instability was a function of the diversity and distribution of vegetation on potentially unstable slopes. Well-vegetated slopes were more stable.

Root strength can also vary with topographic position. Hales et al. (2009) investigated the spatial variability of root network density and strength in the southern Appalachian Mountains in North Carolina by measuring the distribution and tensile strength of roots from soil pits on topographic noses and hollows. They found that roots from trees on noses had greater tensile strength than those found in hollows, a pattern suggesting that not only does vegetation help stabilize topography but that topography affects vegetation, specifically, root strength (presumably due to differences in soil moisture). Trees on noses provided more effective root cohesion than those in hollows, a pattern that would increase further the propensity for landslides to occur in hollows.

The variability of root reinforcement with tree species, root diameter, tree diameter, topographic position, and time after timber harvest complicates quantitatively predicting the effect of root reinforcement on slope stability. The evidence is convincing that taking trees off slopes reduces root reinforcement and allows soils to fail on slopes more easily, i.e., in smaller precipitation events; however, this effect is difficult to incorporate into landscape-scale slope stability models due to the tremendous spatial variability not only in root strength but in other properties that influence slope stability, such as regolith depth and hydraulic conductivity, and the influence of bedrock fractures on soil saturation. There is no ambiguity in the science indicating that clear-cut slopes, from which trees have been removed, are more likely to fail than similar slopes under mature forest. However, managing timber-harvest-related slope instability is difficult because it is impossible to identify with certainty which potentially unstable slopes will actually fail in a particular storm. [**Figure DD5.5**].

Debris flows off a steep, clear-cut slope, Stillman Creek, Washington. The timber company's application to the State Department of Natural Resources before harvest reported that the site had been inspected and was found to have no potentially unstable slopes. [Photograph by S. Ringman, from *Seattle Times*.]

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WORKED PROBLEM

Question: Using the infinite-slope model, what is the maximum stable angle for both dry and saturated sand with no cohesion and a friction angle of 37 degrees? How does this stable angle compare to that of more cohesive material such as till or clay?

Answer: For dry cohesionless materials, the maximum stable angle is the friction angle, ϕ, in this case, 37 degrees. For the failure of a fully saturated, cohesionless soil like coarse sand (FS = 1.0, C = 0, and m = 1.0), eq. 5.8 reduces to $\tan\theta = [[(\rho_s - \rho_w)/\rho_s] \tan\phi]$, which may be approximated by $\tan\theta \approx 1/2 \tan\phi$ (since for most soils $\rho_s \approx 2\rho_w$). This indicates that sandy slopes steeper than about half the friction angle tend to fail if saturated. Thus, when saturated, cohesionless sand with a friction angle of 37 degrees will fail when the slope is about 23.5 degrees. At higher slopes where $\theta \geq \phi$, cohesionless soils tend to slide even when dry; the soil mantle rarely stays on such steep slopes unless there is significant root reinforcement. Soils with even modest amounts of cohesion can stand at much steeper angles over length scales shorter than typical hillslope lengths. For example, excavations in clay (and other cohesive materials like glacial till) can hold vertical faces of up to several meters in height, as can riverbanks, especially if reinforced by roots that provide apparent cohesion.

The 68th UN General Assembly declared 2015 the International Year of Soils (IYS).

The Food and Agriculture Organization of the United Nations has been nominated to implement the IYS 2015, within the framework of the Global Soil Partnership and in collaboration with Governments and the secretariat of the United Nations Convention to Combat Desertification.

> *The International Year of Soils will help us pave the road towards sustainable development for all and by all.*

José Graziano da Silva, FAO Director-General

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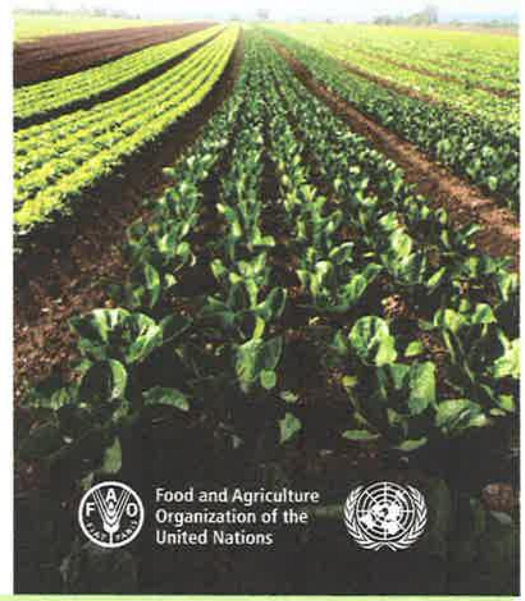
2015 International Year of Soils

healthy soils for a healthy life



Where the Water Begins

Land Management Practices for Marine Shoreline & Bluff Property Owners

King Conservation District
May 31st, June 7th & 21st, 2008

6a. Attachment F

Puget Sound's Nearshore Habit

What is the nearshore?

Nearshore habitat comprises the beach, the upland adjacent to it and the intertidal area. This habitat forms an essential link in the food web of Puget Sound and is an important fish and wildlife corridor. Shallow marine waters are home to sensitive young fish and shellfish and provide an important feeding area for fish, birds and even mammals.

Muddy shores are best known as habitat for commercial and recreational shellfish such as oysters, geoducks and crabs. Eelgrass beds are among the most important sites where herring schools lay their roe. Small worms, mollusks, crustaceans and forage fish inhabiting muddy shores are prey for young salmon, sole and flounder, as well as resident and migrating shorebirds.

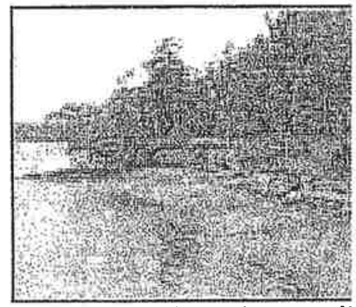
The most common type of shoreline along the inland sea contains a mixture of mud and sand along with coarser gravel and cobbles. This variety of bottom materials supports a great diversity of living creatures: seaweeds clinging to rocks; crab and shrimp scavenging the mud for food; clams burrowed between cobbles; and fish, birds and seals prowling for prey.

What is happening?

Human development has already taken a heavy toll on Puget Sound nearshore habitats. An estimated 58 percent of the original coastal wetlands are gone. Dikes, port development, and commercial and residential building have all impacted these critical areas. Many sand, gravel and cobble shorelines have been dredged, paved or altered by bulkheads. In Seattle and Tacoma, areas which were once expansive intertidal marsh, the losses are almost 100 percent. Despite our heightened awareness, there is a continuing alteration and loss of nearshore habitat, incrementally from one residence to the next.

What should be done?

The Puget Sound Water Quality Action Team is currently working to identify the most significant threats to nearshore habitat. We recognize that the current regulatory system is not working as it should to protect the nearshore. We need better inventory information on the types of nearshore habitats in Puget Sound and the functions they provide. Restoration efforts are needed, particularly in areas that have experienced huge losses of critical habitat.



Photography courtesy of I

What can you do?

Whether you live on the shoi
or are an occasional visitor, y
can be a steward of Puget So
nearshore environment. Volı
with a monitoring group, pic
litter, help with a revegetatic
project or just take the time
back and watch the critters t
live along this glorious Soun

State and Local Part

As part of the Action Team, t
following state agencies and
partners are involved in hab
protection activities:

- Department of Natural Resources (inventories nearshore habitat, owns a manages tidelands)
- Department of Ecology (provides technical assista and guidance materials fc Shoreline Management A
- Department of Fish &Wilc (administers Hydraulic Ap Permits and provides tech assistance)
- Local governments (deve and administers shoreline master programs and crit areas ordinances)
- Tribal governments (inve and protects nearshore ai reserved land)

adjacent shoreline developments and residential farming and forestry practices further upland.

LARGE COMMERCIAL AND INDUSTRIAL DEVELOPMENT

Regulators expressed concern about the siting of large structures and developments in the nearshore environment. Effects associated with large development projects vary greatly depending on individual project proposals. The dominant concerns include the inability to adequately protect extremely sensitive areas of the shoreline, the lack of information available to substantiate potential impacts to aquatic and nearshore marine resources, and the inability to adequately mitigate for impacts on resources.

Cherry Point, in Whatcom County, was cited as an example of an extremely significant nearshore area where a large development could tremendously impact marine resources. Cherry Point provides approximately half of the spawning ground for herring in Puget Sound. Regulators have long known of the area's importance, but the local land-use plan does not prevent development proposals. Several people interviewed cited Cherry Point as a situation where a permanent protective measure should be taken to protect the resources and preempt development proposals, rather than continuing to battle over individual permits.

VEGETATION REMOVAL

Land clearing occurs with most development projects, but nowhere is it of as much concern as at the water's edge. Clearing vegetation removes a source of shading at the shoreline, decreases the contribution of organic debris into the water and depletes the upland-edge habitat for wildlife species. In areas with steep and eroding bluffs, the native vegetation is usually the best tool for keeping the bluff intact and minimizing erosion.

Some local governments provide guidelines for the removal of vegetation in their shoreline master programs, but most regulators admit it is extremely difficult to enforce. Vegetation that is spared during the construction process is often incrementally removed over time to improve views or expand landscaping structures. Restoring an over-cleared area is difficult unless the landowner is committed to replanting, watering and nurturing new plants.

FAILING ON-SITE SEWAGE SYSTEMS

Failing on-site sewage systems contribute fecal bacteria and nutrients to the nearshore environment in areas of Puget Sound. Some jurisdictions have taken strong measures to locate failing systems while other areas are just beginning to address the issue. Several county officials stated that failing septics and their impact on nearshore water quality are a primary concern, more so than physical alterations to the shoreline.

SHORELINE ARMORING

Many people build artificial structures, such as bulkheads and seawalls, on their shoreline property. Referred to as shoreline armoring, this very common practice is a primary concern of state and some local regulators. While most shoreline managers consider shoreline armoring on residential property a serious problem, many property owners view bulkheads as a necessary addition to waterfront homes to control erosion, maintain real estate values and provide a tidy landscaping feature for the front of their home. Shoreline armoring also occurs with commercial and industrial development projects, although it requires a different permitting process.

Shoreline armoring causes problems for nearshore habitats because it interferes with the coastal erosion process and requires clearing of natural vegetation. The natural process of bluff erosion is critical to maintaining a supply of sediment to the beach. Constructing a bulkhead at the bottom of a feeder bluff cuts off the supply of new sediments, and the continuing wave action and littoral drift can result in localized beach loss and eventually accelerated, localized retreat of the bluff (Macdonald, 1995). Concerns also focus on the permanence of the damage, i.e., the cumulative effects of armoring within a given geographic area, and long-term effects on species that depend on the intertidal zone for portions of their life-cycle. Further information on the relationship of armoring

Coastal Training Program Washington

Coastal Processes on Puget Sound

Evolution of Puget Sound shoreline

The Puget Sound region has been shaped by repeated glaciations, the most recent of which filled the Puget Lowland as far south as Olympia about 16,000 years ago. The glaciers shaped the terrain, forming the pervasive north-south ridges as well as the deep troughs that became the Sound itself. The glaciers also brought the glacial till, the sand, and the gravel, that form our soils and our coastal bluffs.

Following the retreat of the ice, changing land levels and changing ocean levels led to a complex *sea level* history, but by about 5000 years ago, sea level reached approximately its current position. Since then, wave action has gradually cut into the steep slopes that surround the Sound, creating both our steep *coastal bluffs* and the bench, or *platform*, on which we find our beaches.

Waves and sediment movement

Winds blowing over the water generate waves. The stronger the wind and the longer the distance of water over which they blow (the fetch), the larger the waves. When waves approach the shore, they begin to steepen and eventually break. Wave action moves beach sediment both up and down the beach, depending on the size and shape of the waves and on the size of the sediment. Some storms can move sand offshore at the same time that they carry gravel to higher points on the beach. Because winter storm waves differ from more gradual summer waves, many beaches show distinct changes from one season to the next - often sandier and broader in summer months, gravelly and steeper in the winter.

Littoral drift and littoral cells

Waves typically approach the shore at an angle, creating *longshore currents* and moving sediment by a process called *littoral drift*. If you have ever observed sand built up on one side of a fallen tree or boat ramp and eroded on the other, you have seen evidence of this process.

Our convoluted shoreline leads to the development of discrete *littoral cells*, in which littoral drift can be mapped. These cells may be several miles in length, or just a few hundred feet. Generally, a littoral cell includes a source area for beach sediment - a stream mouth or an eroding bluff, and an area where sediment accumulates - typically a low-lying *sand spit* or *barrier beach*.

Shoreline erosion

Wave action gradually erodes beaches and the toes of coastal bluffs. Over hundreds of years, steep slopes are formed that are prone to erosion and landsliding when soils become saturated, a large storm strikes at high tide, or an earthquake occurs. Although shoreline erosion tends to occur in short, sudden events, long-term erosion rates on most Puget Sound shorelines are usually less than a few inches per year. Three feet in 30 years might be typical of many shorelines, but rates can vary over short distances.

Eroding coastal bluffs are the primary source of sediment for Puget Sound beaches. Well-intentioned efforts by property owners to prevent shoreline erosion eventually starve beaches of sediment, causing erosion rates to increase elsewhere, leading to the loss of the high tide beach, and modifying beach ecology.

Sand spits and barrier beaches

Where littoral drift accumulates at points along the shore, sand spits and barrier beaches typically form. These low-lying features consist entirely of sand and gravel, are characterized by drift logs and dune grass, and frequently shelter lagoons and salt marshes. These beaches take many forms and represent some of our most prized shoreline -- examples include Dungeness Spit (Sequim), Point Wilson (Port Townsend), Perego's Lagoon (Whidbey Island), and West Point (Seattle). Many have been heavily modified by human development. These beaches are also vulnerable to erosion and changes when natural sources of sediment are cut off by bulkheads or jetties.

Beach Types

Beaches on Puget Sound are incredibly diverse. One can find rocky headlands, steep gravel beaches, and sandy shorelines all within a small area. The composition of a beach is related to wave energy (waves can sort coarse and fine sediment and large waves can move cobbles that small waves cannot), the source of the sediment (beaches supplied by the erosion of coarse gravel bluffs will differ from those fed by erosion of sandy material), and the position of the beach in a littoral cell (boulders and cobble tend to be found near their erosional source, whereas sand can be moved large distances and will accumulate in spits and broad shallow embayments).

Groins and jetties

Groins are structures built across the beach specifically to trap sediment moved by littoral drift. They may be successful in some situations, but are strongly discouraged since they tend to aggravate erosion elsewhere. Any structure, or even a natural feature such as a rock headland, can act as a groin. *Jetties* are larger structures generally built to protect the entrance to a marina or river channel. As with groins, they disrupt the natural flow of beach sediment and can result in significant erosion problems downdrift.

Bulkheads

Bulkheads (or *seawalls*) are structures built along the shore to protect against erosion. They may be constructed to retain and protect fill material placed over the beach or they may be built along an eroding bank to reduce wave erosion. If built correctly, they may reduce wave erosion, but they may not prevent further landslides and erosion from occurring higher on the slope. Seawalls do not stop the beach itself from continuing to erode and may actually exacerbate the loss of the beach by reflecting wave energy downward and by starving the beach of its natural source of sand and gravel.

Recommended reading

John Downing, *The Coast of Puget Sound*, University of Washington Sea Grant, 1983.

Thomas Terich, *Living with the Shore of Puget Sound and the Georgia Strait*, Duke University Press, 1987.

Department of Ecology: Internet Resources

Puget Sound:	http://www.ecy.wa.gov/programs/sea/pugetsound/
Shoreline Air Photos:	http://www.ecy.wa.gov/apps/shorephotos/
Landslides:	http://www.ecy.wa.gov/programs/sea/landslides/
Coastal Maps:	http://www.ecy.wa.gov/programs/sea/SMA/atlas_home.html

Hugh Shipman, coastal geologist, Shorelands and Environmental Assistance Program
Department of Ecology, 3190 - 160th Avenue SE, Bellevue WA 98008-5452

Shallow landslide

Large landslide

Factors Affecting Slides

The occurrence of landslides is governed by numerous factors, though geology, hydrology, and slope steepness are the most significant. Most landslides on Puget Sound occur in response to either heavy precipitation or elevated groundwater conditions (Thorsen, 1987). Different rainfall regimes may lead to different kinds of slides, reflecting the ability of heavy precipitation to saturate shallow soils or of extended wet periods to lead to a rise in regional groundwater levels. During the winter of 1996-1997, two major episodes of landsliding followed heavy rainfalls, a majority of which were relatively shallow failures. In contrast, during the winter of 1998-1999, shallow landslides were infrequent, but prolonged wet conditions led to the reactivation of numerous large, deep-seated landslides (Shipman, 2001). Geologic and hydrologic conditions along with topography and landuse profoundly effect the stability of a given shoreline bluff. The role of earthquakes on the failure of bluffs is poorly understood, however it is generally accepted that a slope that is on the threshold of failure can fail due to the additional stress and strain of a strong seismic event. Recent topographic mapping has identified or confirmed the presence of several large landslide features along the shoreline in close proximity to mapped faults.

Most landslides in the region occur where permeable sand and gravel units lie directly on top of less permeable silts and clays, allowing a perched water table to develop and soils to become locally saturated (Tubbs, 1974). The most common scenario is where advance outwash overlies silt and clay deposits. Groundwater percolates downward in the porous outwash and laterally toward the bluff face along the contact with the finer grained underlying material. When water levels rise, increased pore pressures lead to weakness and failure. Similar geologic conditions exist where glacial sediments overlie bedrock and where recessional outwash is found above impermeable glacial till. Steeper slopes are generally more prone to failure as gravitational stresses are greater, but variations in strength and differences in hydrologic conditions make it difficult to predict landslides based on slope alone. On coastal bluffs, erosion of the toe by wave action ultimately leads to steepening of the slope and the increasing likelihood of failure, but whereas toe erosion is a relatively slow process on most Puget Sound bluffs, landslides typically occur in response to transient increases in groundwater or soil saturation. As a result, wave action and undercutting may set the stage for future slope failures but rarely precipitate landslides.

A line of moisture-loving red alders or willows growing across a slope might reflect colonization of bare ground following a recent slide—or a zone of groundwater seepage marking the junction between an impervious clay layer and overlying sandy soils. In either case, there is a potential for unstable slope conditions that should be investigated further.

Downed trees may reflect diseases such as root rot, shallow rooting and wind-caused blow down, poorly planned tree removal that exposes previously stable trees to new wind stresses, or slope disturbances that undermine the trees' root mass. Curved tree trunks such as shown in Figure 3-5 usually reflect slow, gradual soil creep, while the jumbled appearance of "jackstrawed" trees often results from a slump or earth flow. Dead trees in the latter situation probably indicate the roots were sheared or broken loose during the earth movement.

Banks or bluffs devoid of vegetation typically suggest the site is either too steep to support vegetation (near vertical bluff faces of glacial till, for example), or that recurrent erosion and slumping preclude plant establishment (retreating sandy bluffs, for example). Bare bluffs can also indicate recent or ongoing slope failure due to wave-related toe erosion and upslope slumping (e.g., feeder bluffs).

4.4.2 Vegetation and Slope Stability

The presence or absence of vegetation on the shoreline banks and bluffs of Puget Sound—and how that vegetation is managed during and after site development—usually plays a crucial role in determining local slope stability. Some of the ways in which vegetation cover influences slope stability are illustrated in Figure 4-15.

The presence of vegetation reduces the potential for slope erosion in at least three different ways. First, plant roots, large and small, provide a fibrous web that stabilizes and anchors the soil. Second, plant cover intercepts the falling rain, reducing the direct impact of raindrops on the ground surface and protecting the soil from surface runoff and erosion.

Dense groundcovers, especially grasses, reduce runoff velocity and act as filters trapping soil particles that would otherwise be washed downslope. Thirdly, vegetation, and associated plant litter, the partially decomposed remains of roots, stems and leaves, moderate critical soil moisture relationships. By slowing runoff, vegetation enhances infiltration; associated litter acts like a sponge, holding the moisture and releasing it slowly over an extended period. Plants can also play an important role in dewatering unstable slopes.

4.6 Human Disturbance

Vegetation Management: A Guide for Puget Sound Bluff Property Owners (Menashe, 1993) begins with a daunting scenario of bluff development. The bluff top is cleared and graded, trees are cut to open up the view, and debris pushed over the bluff edge. The home is sited close to the bluff crest to take full advantage of the view. Utility trenches, roof and footing drains, and a septic system are all installed. Grading activities and construction traffic compact the upland soil, reducing its porosity and causing new topsoil to be brought in for landscaping. A stairway is constructed to the beach causing more vegetation to be cleared from the bluff face.

Each of these human disturbances to the natural bluff setting creates or aggravates a potential destabilizing factor that will affect longer-term slope stability. Vegetation clearing eliminates the soil binding action of plant roots. Soil compaction, trenching, and the addition of a septic system, all have the potential to alter surface water runoff and groundwater relationships. The addition of a home and new topsoil each increase the load at the top of the bluff slope. Not surprisingly, this all adds up to a recipe for increased slope erosion, soil slumping, and the potential for a serious landslide.

Figure 4-22 diagrams many of the ways in which bluff top construction can directly and indirectly influence surface and groundwater movements in coastal bluffs—as well as some other causes of bluff instability. Figure 4-23 illustrates some homeowner "solutions" to typical shoreline bluff instability concerns. Clearly, considerable time and resources have gone into protecting the homeowner's investment in shoreline property. Note, however, that property protection has been achieved at the cost of disrupting many of the "landscape

- Beware of recommendations that tree removal for site development is "routine." As Menashe (1993) notes, "...the overwhelming conclusion is, that in the vast majority of cases, vegetation (especially well-rooted, mature trees) helps to stabilize a slope."

- Consider how the tree or shrub species being cut will respond. For example, most conifers will not resprout, but willow, red alder, bigleaf and vine maple often do.

- If trees *must* be removed, try to leave the stumps undisturbed. Their root systems will offer some slope stability and erosion benefits while new replacement growth is developing.

As with tree removal, **tree topping** is strongly discouraged. Despite common arguments promoting topping—it reduces height, protects views, decreases wind resistance—it has been clearly demonstrated to be a poor, shortsighted, and damaging practice (Menashe, 1993). Several practical tree trimming practices are available as successful alternatives to both tree removal and topping. Some of these are illustrated in Figure 5-6.

Menashe (1993) also addresses a variety of other issues relating to shoreline vegetation management:

- The values and limitations of lawns—shallow rooting limits erosion control value (good groundcover for septic drainfields); becomes saturated easily, resulting in ponding or runoff.

- The importance of using deep-rooted groundcovers near the crests of slopes (e.g., salal, Oregon grape, wild rose, etc.), to better reduce surface water runoff and thus soil erosion.

- Avoiding construction damage during development—soil compaction, burial or exposure of tree roots, mechanical injury of trees by heavy equipment.

6a. Attachment F

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Value, Benefits and Limitations of Vegetation in Reducing Erosion

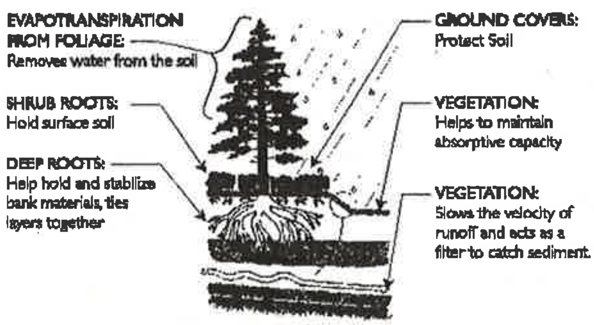
Trees, shrubs, and groundcovers can maintain slopes and reduce erosion from surface water, shallow groundwater and, to some extent, coastal processes. Evergreen trees and other vegetation are most valuable and able to protect soil and remove water during the winter months when deciduous plants are dormant. A diverse mix of both evergreen and deciduous plants provides the greatest protection.

Plants can also have value as sight and sound barriers, discourage access to hazardous areas, and define space in a yard. Native plants enhance wildlife habitat by providing nesting and hiding cover, food, and safe travel corridors. Once established, native plants require little maintenance or care. Species should be chosen for their ease of establishment, adaptability, usefulness, and availability.

Extensive lawns, especially in the vicinity of the bank crest, should be avoided because grass tends to increase surface-water sheetflow during wet conditions when soils are saturated. Low-growing evergreen or perennial plants should be established on the upper crest of the bank.

THE VALUE OF VEGETATION IN STABILIZING SLOPES

FIGURE 1. ROLE OF VEGETATION IN REDUCING EROSION AND STABILIZING SLOPES. (MENASHE, 1993)

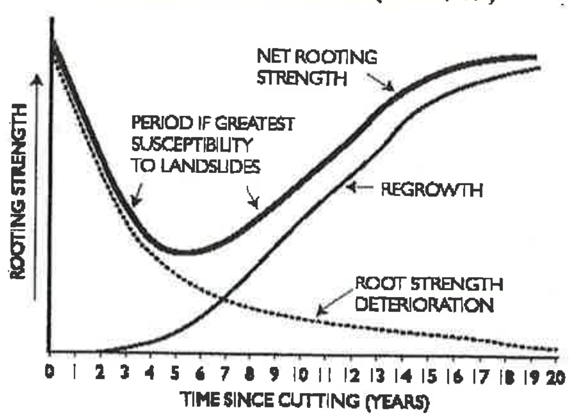


1. Foliage intercepts rainfall, causing absorptive and evaporative losses that reduce surface water runoff and erosion.
2. Evergreen trees and shrubs continue the metabolic activity known as evapo-transpiration, which extracts moisture from the soil, throughout the year. As logging or clearing occurs, water table levels rise, and soils remain saturated for longer periods, reducing soil cohesion and increasing the rate of land slides.
3. Roots reinforce the soil, increasing lateral soil sheer strength and cohesion during saturated conditions. Many slopes can persist beyond their angle of repose and remain stable as a result of the complex root networks within soil blocks.
4. Tree roots anchor soil strata vertically and laterally by means of large-diameter structural roots. These roots may extend well beyond the tree's canopy or crown.
5. Roots, especially the fine feeder roots of trees, shrubs and groundcovers, bind soil particles at the ground surface, reducing their susceptibility to surface erosion and slumpage during saturated soil conditions.
6. Large trees can arrest, retard, or reduce the severity and extent of failures by buttressing a slope. This works in much the same way as retaining walls. In the case of trees, though, the system is to some extent self-repairing, and it becomes progressively stronger over time, whereas engineering structures are strongest when installed and become progressively weaker over time. Obviously, planted trees need adequate time to develop root systems and become effective in stabilizing slopes.

LIMITATIONS OF VEGETATION

The limitations of vegetation in preventing, reducing or arresting slope failures and erosion is often due to previous land management practices such as logging, topographic alterations, increased or channelized surface water flow, and wholesale clearing. Once initiated, slope failures require an expenditure of time, effort, critical planning and money to stabilize them successfully. The use of vegetation in particular requires foresight and several years of monitoring and maintenance until plants are established and effective. Establishment can take up to three years. It can take up to 15 years for shrubby vegetation to develop the values discussed above, even longer for trees to reach sufficient stature to be effective. The impacts of tree cutting on steep slopes can take several years to become apparent, as illustrated in figure 2.

FIGURE 2. CONCEPTUAL GRAPH INDICATING ROOT STRENGTH DETERIORATION AFTER CUTTING (R. SIDLE, 1984)



Landowners need to be aware that not all vegetation provides effective erosion control. Just because it is green does not necessarily mean it works. Such common species as Himalayan blackberry, horsetails, English ivy, and red alder are often present on disturbed slopes and have limited erosion control value. Blackberry and ivy, in particular, tend to discourage more desirable vegetation from becoming established.

In some situations a combination of geotechnical engineering and vegetative techniques are required to assure a practical solution to slope problems. The best time to employ inexpensive relatively vegetative means is before severe failures occur. Note: It should be clearly understood that unusually harsh climatic conditions prior to full development of a vegetative root matrix could result in failure or partial failure of such a slope stabilization system. Landscape contractors should have an understanding of the processes affecting slopes, techniques to be employed to ensure success, and the potential hazards of working on steep slopes in vulnerable areas.

There are several situations where vegetation is relatively or completely ineffective in protecting a slope from failure. These include: (1) lower banks subject to wave attack; (2) areas of deep-seated geologic instability; (3) bluffs near vertical; and (4) unstable areas too wet or dry for vegetation to become established.

RECOMMENDATIONS

Plantings in areas that have not recently been subjected to slope failures are a wise investment. Preventive measures, employed before serious problems occur, are relatively inexpensive. Bear in mind that plantings of more desirable species to replace existing species such as red alder should be well established (2-3 years) before alders are removed, in order to maintain adequate soil-binding benefits within the effective root zone (ERZ) of the cut trees. The ERZ can be approximated as a one-foot radius of lateral root extent for every inch of diameter of the tree's trunk. Preparatory to planting, alders (as well as cherry) can be thinned to a spacing that will not compromise slope integrity during the establishment period. Tree cutting on slopes without replanting can have serious future consequences as illustrated in figure 2.

Proper selection of shrub and tree species for position on the slope will minimize view maintenance requirements while greatly improving slope stability. Care should be taken in selecting species that thrive under site-specific conditions found locally on the slope. These include soil moisture, light/shade, and rooting type.

by continued high-impact development practices. Critical area buffers are inadequate. Wetlands, streams, estuaries, and marine waters continue to be degraded as conversion logging and development proceed.

PART OF THE SOLUTION: EDUCATION

Preserving effective native vegetation complexes is a simple, effective, and easily implemented measure that can be employed immediately at any scale. Educating landowners, equipment operators, contractors, builders, landscape architects, and others should be a high priority. Education relating to the benefits of low impact development practices can be implemented independently of other efforts.

WHY PRESERVE NATIVE VEGETATION?

Vegetation protects soil from erosion and reduces surface water runoff in many ways (see figure 1, Effects of Vegetation in Minimizing Erosion). Live plant foliage and forest litter reduce the impact of rainfall and increase the absorptive capacity of the soil. Stormwater is held onsite and released slowly. Groundcovers intercept and slow rainfall and their roots hold soil particles in place. Groundcovers reduce runoff velocity and filter out suspended soil particles during storms. Shrub and tree roots, especially fibrous feeder roots, provide a restraining web that increases soil cohesion and stabilizes soil. Tree anchoring roots often penetrate deeply into soil blocks, increasing soil shear strength and resisting shallow mass soil movement. Roots also promote soil porosity and permeability. Evapotranspiration by plants reduces soil moisture and delays the onset of saturation and runoff. Native plant communities represent a complex interrelated biotic association of plants, animals, and microorganisms which have adapted to our region's ecological conditions over thousands of years. The ability of these plant communities to provide "passive" watershed protection is phenomenal. Vegetated watersheds exhibit lower peak flows, lower total discharge volumes, and increased lag-time between rainfall and runoff than do watersheds with a high percentage of forest cover removal and impervious surfaces. (See figure 2, Impacts of Urbanization on Stream Flow).

Vegetation also provides wildlife habitat, sight and sound screening, recreational opportunities and

FIGURE 1. EFFECTS OF VEGETATION IN MINIMIZING EROSION (MENASHE, 1993)

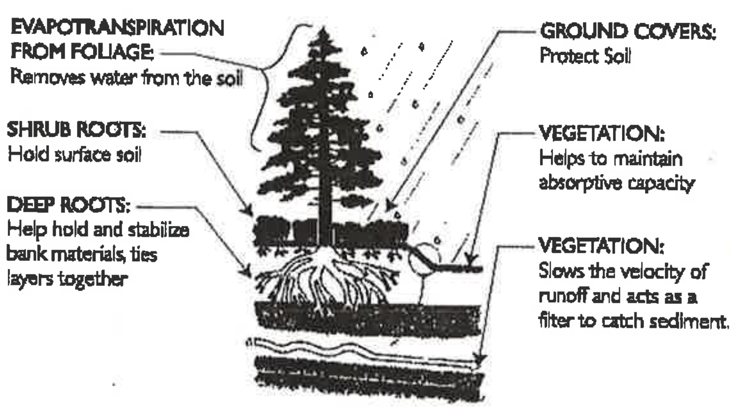
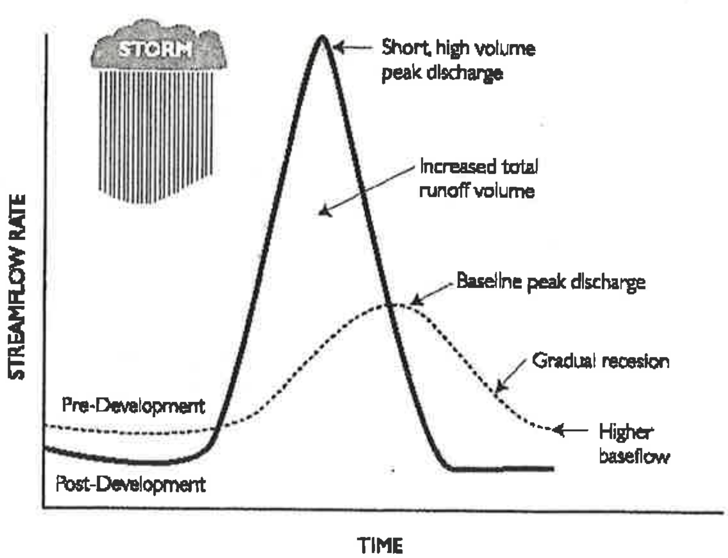


FIGURE 2. IMPACTS OF URBANIZATION ON STREAMFLOW (SCHUELER, 1987)



aesthetic amenities. Site development, landscaping and maintenance costs are lower when vegetation is preserved. Reduction in slash and burnpile volumes contributes to improved air quality and minimized disposal costs.

WHAT VEGETATION IS MOST EFFECTIVE?

The most effective plant communities are multi-age forested assemblages which have a high structural and species diversity. High value sites include those with a wide variety of evergreen and deciduous trees, shrubs and groundcovers. Absence of invasive exotic plants is a plus. The presence of large downed wood is a valuable asset. Valuable understory species include swordfern, salal, evergreen and red huckleberry and Oregon grape.

The least effective plant communities are characterized by minimal structural and species diversity and a high incidence of invasive exotic plants, such as Himalayan blackberry, English ivy, Japanese Knotweed, and Scot's broom. Not all native vegetation provides effective erosion control. Forest lands dominated by red alder and stinging nettle are often indicative of degraded sites and provide few hydrologic benefits.

It is important to "read the land" and at least qualitatively assess the value of the vegetation present. Previous management and land use history often determines what is growing where. Obvious signs of past or recent clearing, grading, soil compaction, and erosion usually indicates a degraded site that may have reduced value in preservation efforts.

Physical characteristics of the site will also dictate what plants are present and the extent of potential runoff problems. Soil, geology, slope, aspect, topography, site hydrology and off-site influences are important factors to evaluate when assessing the value of vegetation's influence on stormwater management.

HOW TO PRESERVE VEGETATION?

Each site is different and offers unique challenges and opportunities for preservation efforts. It is critical to evaluate the site with preservation in mind during the planning stage. Identify high-value natural areas. Locate buildings, roads and infrastructure to avoid impacting valuable areas. During site development, retain healthy, windfirm trees. Fence or otherwise limit entry into preservation areas during construction. Salvage valuable native plants and nurse logs from areas to be cleared. Avoid grade changes near large, well-established trees. Reduce hydrologic modifications. Reduce impervious surfaces and lawn areas. Prohibit dumping of concrete washout and other chemicals on the site.

CONCLUSION:

Extensive clearing and grading are common practices associated with urbanizing areas. Replacement of existing naturally vegetated areas with impervious and semi-impervious surfaces increases stormwater runoff and adversely impacts developing watersheds in a variety of ways. The hidden environmental and economic costs to society of this on-going process of watershed degradation are poorly understood by the general public. Conventional "best management practices" (BMPs) and engineered hydrologic controls are ineffective in mitigating development influences. They are, at best, only a tool in mitigating adverse watershed impacts. They are not a solution.

Preservation of naturally vegetated areas can be a "passive" stormwater management tool that effectively reduces cumulative watershed function deterioration while providing other benefits and amenities.

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TREES, SOILS, GEOLOGY, AND SLOPE STABILITY

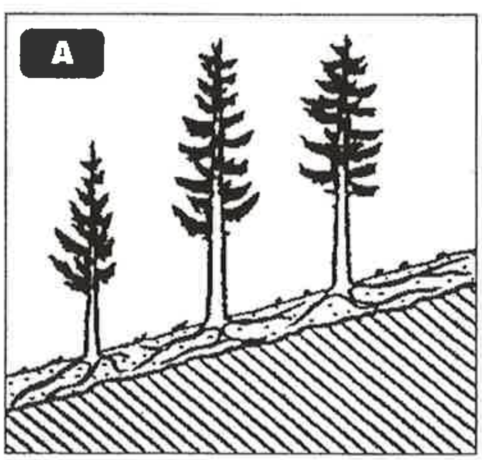
The following drawings and narratives are provided as a very simplified representation of how trees may influence slope stability on Puget Sound marine shorelines. They illustrate several generalized combinations of soil depth, stratigraphy, and tree rooting. The degree to which trees may influence stability on a given slope is a complex function of various specific, interacting physical, biotic, and human-related factors.

Physical factors include slope geometry and gradient, geologic materials, stratigraphy, hydrology, and the local effects of shore processes. Climatic variability can alter the dynamic equilibrium of a slope in significant ways.

The species mix of trees as well as their spacing, age, vigor and health, influence how effectively trees can stabilize slopes. The successional stage and complexity of the associated plant community can be a significant factor. The role of associated vegetation, though significant, in effecting hydrologic conditions, soil formation, and other factors which may influence erosion rates and slope stability is not addressed here.

Forested marine slopes are often barely stable, have adjusted to the various forces acting on them and have developed a delicate equilibrium. They are sensitive to alterations such as view clearing and tree removal, as well as upland site development such as lot clearing and grading. They may also be highly sensitive to cumulative upslope disturbance and local watershed modifications which effect slope hydrology. Disturbances such as logging, roadbuilding, and urbanization in developing watersheds can significantly alter conditions and upset the dynamic equilibrium of slopes, thereby indirectly causing increased landslide activity on previously stable slopes.

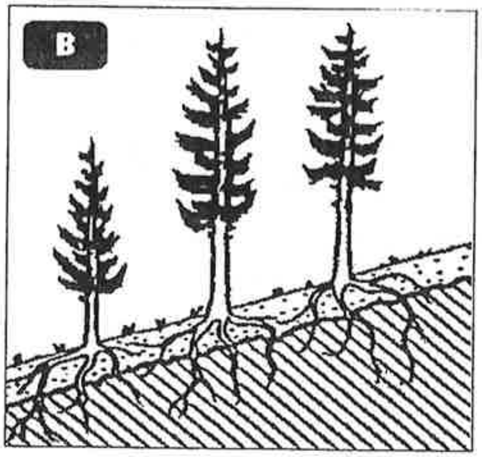
It should be emphasized that the following examples are greatly simplified when compared to actual conditions found on Puget Sound shorelines. For example; our shorelines are often steeper and the subsoils (geologic parent materials) are complex, resulting in erratic concentrations of groundwater, which complicate slope stability assessments.



Type A

Characterized by shallow (less than 3 feet) soils overlaying parent material (competent rock, glacial till, dense silt or clay) which resists root penetration. Surface soils are fully reinforced with tree roots. Lateral rooting, though shallow, often resists slope failures if tree density and distribution is adequate to provide an interconnected root-web matrix. Rooting is plate-like. Roots are at failure plane. Subject to rapid, shallow slides during extreme rain-on-snow events.

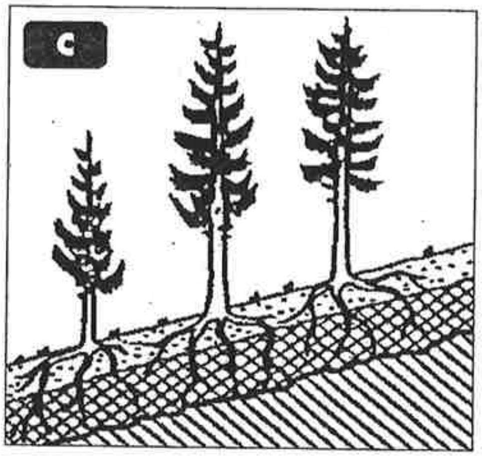
Stabilizing effect of roots: Moderate if not compromised. Tends to become rapidly unstable when disturbed, or subjected to increased hydrological influences. Anchoring - minor. Soil cohesion - high.



Type B

Characterized by shallow (less than 3 feet) soils overlaying parent material (dense sand, glacial till, etc.) which allows significant root penetration. Degree of anchoring into parent material by roots is dependent on the nature of the fractures in the parent material and the predominant tree species. Roots intersect potential failure plane, providing shear resistance.

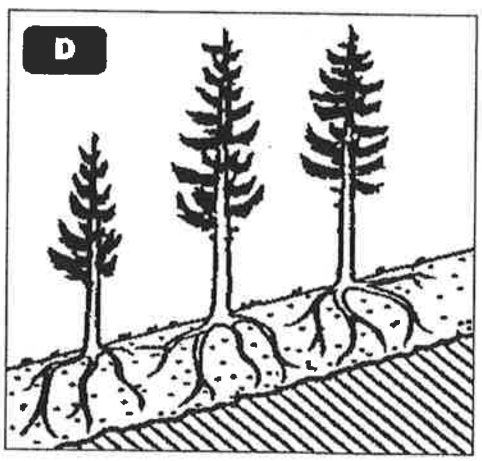
Stabilizing effect of roots: High. Individual trees are stable without a significant dependence on adjacent trees. Both anchoring and soil cohesion benefits are high.



Type C

Characterized by deeper soils (3-12 feet) with a non-distinct transition zone in which soil shear strength increases with depth. Assumptions include: (1) transition zone functions as a drainage moderator, allowing a concentration of groundwater and increased pore-water pressure; (2) failure plane passes through the transition zone; (3) soil zone is more easily penetrated and permeated by roots than in B, above. (Example: sandy loam over loose till over compacted till.)

Stabilizing effect of roots: Anchoring - high.
Soil Cohesion - high.



Type D

Characterized by deep soils where both the failure plane and the soils are deeper than the root zone. The actual depth of the soil for this condition to occur depends on root morphology (depth, spread, etc.) of the particular tree species on the slope. For example, on a slope where Red alder predominates, a relatively shallower soil depth would exhibit Type D conditions, while on a slope forested by Douglas-fir the stabilizing effects would be significantly greater for the same depth.

Stabilizing effect of roots: Anchoring - minor.
Soil Cohesion - moderate.

Illustrations adapted from: Vegetation Influences on Debris Slide Occurrences on Steep Slopes in Japan, Y. Tsukamota and O. Kasakobe. 1984

Prepared for Coastal Training Program by Elliott Menashe (www.greenbeltconsulting.com) 2004

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Tree Removal on Steep Slopes of Puget Sound Shorelines

The mechanical and hydrogeological benefits which trees and other vegetation provide to maintain slope stability and reduce erosion are well documented. Most of the wooded bluffs rimming Puget Sound are in a delicate equilibrium. For example, natural events such as an unusually intense winter rainstorm or human activities such as a concentration of upland runoff or careless logging on the bluff can reduce stability, even trigger landslides. As a planner or permitting agency official, what are your responsibilities regarding tree cutting? Given that there may be downslope impacts, possibly serious hazards to homes or public facilities, do you make decisions regarding tree cutting and/or removal? If so, remember the admonition to physicians: "First, do no harm."

Let's assume that trees have already been cut and downslope residents voice concerns about effects on bank stability. Some questions that may arise:

- Was the cutting authorized by your agency or another agency (e.g., DNR) that has jurisdiction?
- Who owns the land? Property side lines on waterfront/view lots are commonly skewed (Fig. 1). Property boundaries on the face of a bluff are commonly unmarked or inaccessible.
- Who cut the trees or hired the cutter? Timber trespass is not uncommon in such settings. Has a timber trespass occurred?

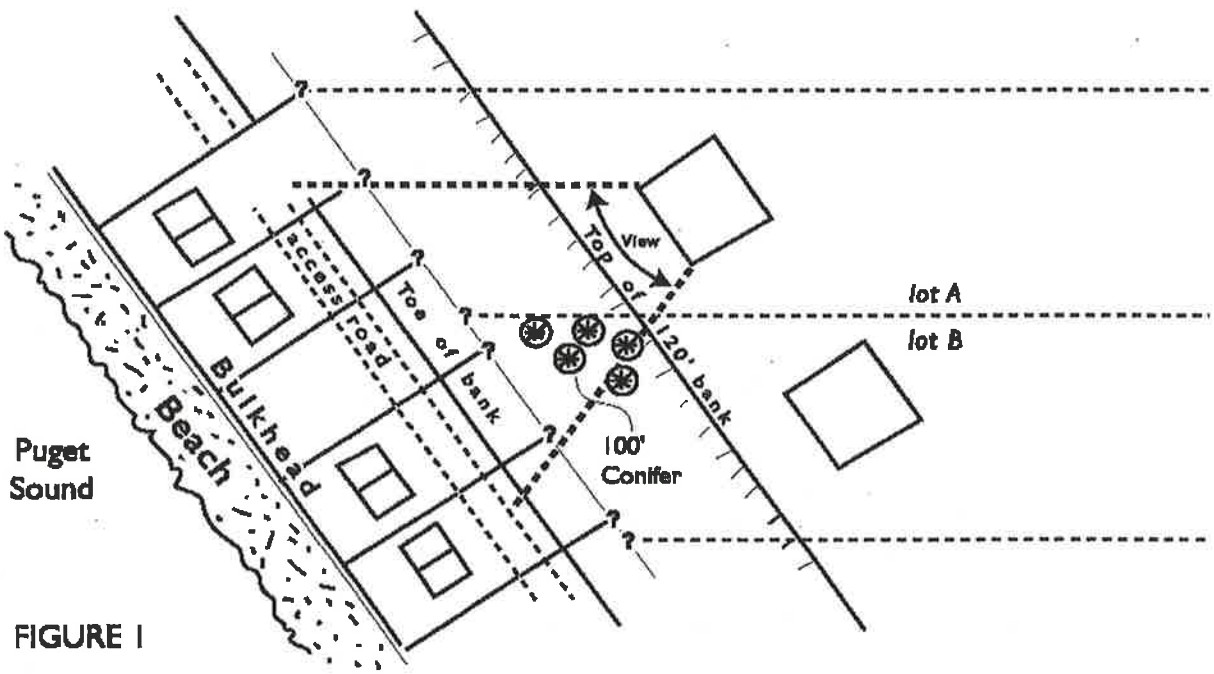


FIGURE 1

Figure 1. Sketch shows a typical scenario for development along shoreline bluffs. Note angle between lot side lines and edge of bank. Trees on lot B partially obscure the view from lot A, a setting ripe for timber trespass and/or legal squabbles. (Skewed property lines where there are no beach homes below can also complicate matters. In cases where wave erosion is at the toe of the bluff, a bulkhead fronting property B would mostly protect the home on lot A.)

Property ownership and cutting responsibility questions are basic to questions of log removal/leave and slope rehabilitation/replanting. As our main focal point here is on removal, an obvious question arises: Who pays for it? A property owner who cuts his or her own trees (after obtaining necessary permits, if any) is obviously responsible for such decisions. What about the rather common situation in such settings of 'timber trespass"? In at least some situations the owner is entitled to triple damages from the illegal cutter. Will the property owner allow access to the site for removal of the downed trees? If so, will that increase his or her liability for accidents or some future slide from their property? Such legal aspects of the problem are not trivial. Economics, including potential liability, may decide what (if anything) is done regarding tree removal, slope rehabilitation, and revegetation.

Upon what can 'damages" for trespass be based? The value of a tree for lumber can be calculated rather precisely on the basis of market factors such as species, size, cost to reach market, and current price. What about aesthetic value? (Some arborists and/or real estate professionals may be able to offer an estimate of the impact of the loss of the trees on property value.) The value of an individual tree or group of trees in relation to their role in maintaining slope stability is even more difficult to quantify, but it is often a significant consideration.

Let's assume that the trees were cut with city or county permission. Assume that the loss of trees will have some detrimental effect on slope stability, both immediately (precipitation interception, transpiration) and long term (loss of root/soil reinforcement, anchoring over time). Assume that the potential for any damage resulting from the instability (e.g., landslides) will be increased by the presence of large woody debris left on the slope. As the planner in the Permit Center who signed off on the cutting, should you insist on removal of the cut trees? (Hint: This slope may slide anyway, whether the logs are removed or not.)

As mentioned, the loss of mature or at least well-established trees has a significant effect on the stability of already marginal slopes. Soil disturbance and the further loss of young trees and brush, as well as the forest floor duff and litter, can further degrade stability. Log removal efforts can seriously disrupt shallow soils and such ground cover. Thus we are faced with two major options: leave the trees where they fell or remove them. Either choice can impact slope stability and legal liability. Logs can be removed with little or no further disturbance of soil and ground cover by what loggers and commercial foresters call "full suspension" techniques.

Logs are lifted, not dragged. This requires specialized heavy equipment both at the top and bottom of a slope (or at least a strong "block" or pulley with a massive anchor at one end). Full suspension can also be achieved by balloons or large helicopters. All such techniques are very expensive and/or impractical or impossible to use in most populated shoreline bluff settings. The 'reach' of a crane from the top or from the base of a bluff is limited, even where such sites are accessible; they are almost useless on bluffs in the 150- to 300-ft range.

Horse logging can minimize soil and underbrush disturbance, but cannot be done on slopes as steep as most of our shoreline bluffs. Tractors and excavators need roads on such slopes, and the logs still must be dragged to the road. Also, the roads themselves leave unstable slopes as well as concentrate storm runoff long after the logging is complete. Thus by process of elimination, we are left with hand labor for removing large woody debris from most steep coastal bluffs.

Assuming that hand labor is the only practical option for removal of downed timber from steep (35+ degree) slopes, let's consider its limitations.

- It is dangerous, hard work, even for the experienced.
- Thus, experienced help can be expensive.
- Amateur do-it-yourself help can be more expensive (i.e., medical, liability)
- There is a limit to the size of material that can be handled (excluding help from gravity, which we are trying to avoid)

Some ways we can minimize these limitations are:

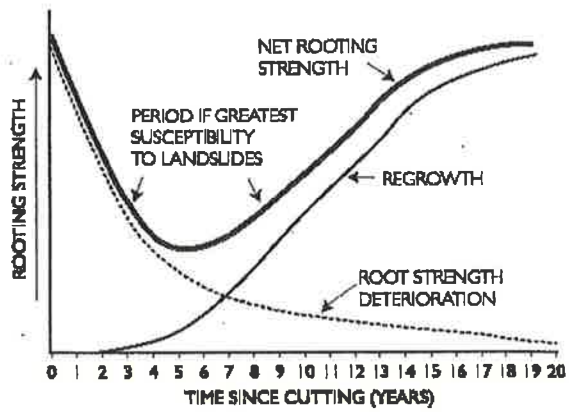
- If there is no hazard (people, structures) below, reconsider. Maybe the logs should be left in place; let nature take its course (i.e., rot and gravity)
- Leave wood in contact with the ground, if possible, to facilitate rotting.
- Work when spring slide hazard is past; remove wood in early fall.
- If a log is oriented within 20 degrees or so of perpendicular to the slope and is supported by a sprouting stump at both ends, leave it.
- Cut (and split?) a log into sizes that can be manhandled.
- Leave tops and limbs smaller than 3- to 4-in. diameter scattered on the slope as ground cover.
- Do not pile tops/limbs, as piles can prevent regrowth (natural or planted) and smother native brush.

In precarious areas directly above a residence, hazards can be minimized by common-sense techniques such as tying a downed tree to a stump before cutting it into logs. Temporary 'cyclone fences' can be strung between standing trees above the downslope home. Experienced woodsmen (for example, cedar cutters) can move wood in ingenious ways with little equipment. Don't try to "fine tune" their plan; every situation of trees, topography, and potential hazard is unique. Perhaps the best conditional constraint would be that no additional disturbance to the slope should occur.

Before ordering removal of large downed trees on a steep slope, the planner/permit official might want to check with their legal counsel. What is at hazard downslope? Do homeowners at the base of the bluff understand the options and potential hazards? For example, a "cartwheel" of firewood from a 3- to 4-ft fir can become lethal if it starts rolling on a steep slope. Who is liable? The wood cutter? The property owner? The agency that ordered or approved the removal? All of the above? (An industrial or commercial downslope property owner might want to make their own plans regarding timber cutting/log removal.)

What about stumps? A stump and its rootball, *if mobilized* into a shallow fast-moving slide (debris avalanche), can add to the future damage potential of the mud and smaller debris. However, removing stumps *will increase* the likelihood of such events. As the roots of many stumps rot, their ability to provide reinforcement and anchoring of the soil/vegetation mat decreases. However, they may still provide that critical role, albeit to a decreasing extent over time, while new trees are getting established. (See figure 2) Generally, stumps of cut trees should not be removed.

FIGURE 2. CONCEPTUAL GRAPH INDICATING ROOT STRENGTH DETERIORATION AFTER CUTTING (R. SIDLE, 1984)



Special mention is warranted for stumps that sprout, thus keeping the stump alive and its roots functioning. Species such as maple, willow, and madrone usually sprout and, after several years, may provide the same slope stabilizing benefits as the standing tree. It is not unusual to see cut-over slopes slide except for the area at and below a single sprouted maple stump. Also, removing a stump on a bluff via hand labor is slow and expensive and creates a bare patch subject to erosion and increased infiltration. Except in isolated instances where a stump is an obvious hazard, they should be left.

If you need to remove large (1-ft+) trees from an area of steep ground (35+ degrees) where property and lives below could be at stake, get a pro. The passing 'blow-hard' who can shrug and walk away from his self-created "accident" won't do. Get a responsible expert (one who is licensed, bonded). That person should be able to tell if a particular site is a 'piece of cake' or will require much finesse. If the hazard potential is great, you might want a second opinion. As a public official, with your signature on the application, carefully exploring all options may save you and your agency later grief and expense.

Mitigation of damage to the slope from tree cutting and removal of debris should be a routine condition of permitting tree removals. Mitigation specifications should reduce both short- and long-term stability and erosion impacts which are likely to occur as a result of tree removal. Measures such as revegetation with suitable native species are often effective if an agency requires adequate monitoring and project maintenance during the establishment period (3-5 years). Vegetative buffers at the crest of the slope, as well as drainage controls of upland and slope surface-water run-off are also valuable mitigation tools.

Cutting of trees and removal of large woody debris from steep slopes can impact slope stability and have long-term legal ramifications for landowners and permitting agencies. Caution and common sense should be exercised in managing steep, often unstable, marine slopes.

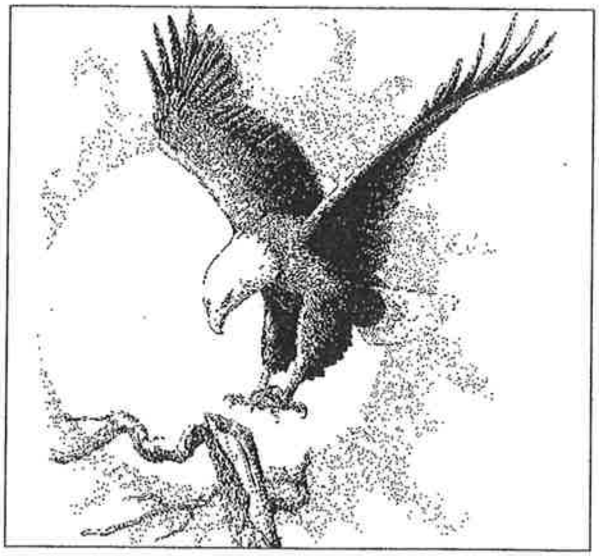


Figure 6. The bald eagle is the Pacific Northwest's largest resident bird of prey, with a wingspan of up to 7½ feet and weights of 8 to 14 pounds. Females are larger than males. (Drawing by Elva Hamerstrom Paulson.)

Ospreys build large nests near water, on top of dead trees or artificial structures that are similar to dead trees, such as utility or nesting poles. They can be found near fresh or salt water, as long as the water can sustain medium-sized fish. As with eagles, ospreys suffered great declines in the past century as a result of DDT and other eggshell-thinning pesticides. Range expansion into formerly occupied areas has been slow due to their strong loyalty to nesting areas. Artificial nest platforms have significantly increased nesting in many areas (Pendleton et.al., 1987).

A variety of hawks including the **Cooper's hawk**, **sharp-shinned hawk**, and **red-tailed hawk** use tall dead trees and branches as places to rest, look for prey, and feed once prey is caught. The tree's height provides the birds with a wide visual range, easy takeoff, and greater attack speed when hunting.

Peregrine falcons are typically found hunting in open areas, especially along marine area bluffs and near other bodies of water that provide habitat for their prey. They are considered a species of special concern by the Department of Fish and Wildlife, and are listed as an at-risk species by the Washington Gap Analysis (see Washington Gap Analysis).

In Washington, peregrine falcons reached a low of four pairs in 1980. In 2000, 56 pairs were counted, doubling the number counted just seven years prior (see WDFW's Priority Species).

Several owl species are seen or heard around wooded marine area bluff properties. The most common species include: The **great horned owl**, **barred owl**, **barn owl**, **western screech owl** and the **northern saw-whet owl**. Visual encounters with owls are relatively rare, because they spend most of the day perched high in trees, inside tree cavities, or in nest boxes.

Adaptable and widespread, the **great blue heron** is found in a wide variety of habitats. When feeding, it is usually seen in slow-moving or calm salt, fresh, or brackish water. Nesting colonies are found in mature forests, on islands, and on or near bluffs that are free of human disturbance and have foraging areas close by. Breeding areas are of concern to Washington Department of Fish and Wildlife biologists. Construction near a colony are particularly damaging, and a 1000-foot buffer zone around colonies is recommended (see WDFW's Priority Species).

Belted kingfishers (Fig. 7) are commonly seen and heard along shorelines in saltwater environments. Kingfishers require sandy vertical banks for nest burrows and clear water so they can see their aquatic prey. The kingfisher nests in burrows dug in sandy banks; two of its toes are fused together and act as a shovel for digging these burrows.

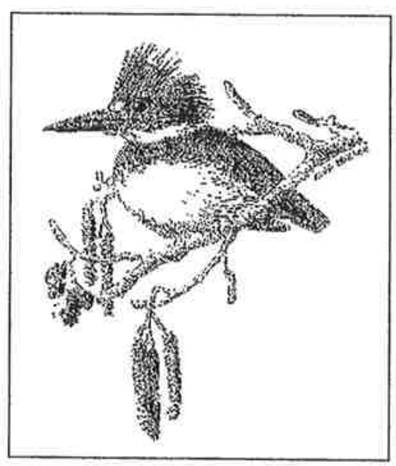


Figure 7. The belted kingfisher is a pigeon-sized bird that is blue-gray above and white below, with a bushy crest, a large, daggerlike bill, and a short tail. (Drawing by Elva Hamerstrom Paulson.)

Pigeon guillemots are seen along many Puget Sound waters. During the breeding season, they can be found on rocky islands and mainland cliffs that are protected from predators, as well as on a variety of man-made structures. The population of pigeon guillemots in Washington is not well known, and has probably declined in recent decades. They are highly vulnerable to oil spills and other pollution, and changing water temperatures. According to breeding bird surveys, the population in Washington has remained stable over the last 35 years. However, availability of suitable banks for nesting is a limiting factor in distribution and abundance.

Woodpeckers, including **flickers** and **sapsuckers** play an important role in wooded bluffs. They eat all life-stages of wood-boring insects that are inaccessible to most other forest birds. Northern flickers, or flickers, eat quantities of carpenter ants.

Holes that woodpeckers create each year for nesting and roosting are used in subsequent years by cavity-nesting songbirds, small owls, ducks, and native squirrels that cannot fully excavate their own nest site.

Clear-cutting forests currently has the most significant impact on **pileated woodpecker** habitat, but pileated woodpeckers are fairly adaptable, which offsets some of the impact from habitat loss. They are, however, currently candidates for endangered species listing by the Washington Department of Fish and Wildlife and are included on the Gap Analysis list of species-at-risk (see Washington Gap Analysis and WDFW's Priority Species for management recommendations).

Northern rough-winged swallows are usually found near water, especially along sandy cliffs or rivers with high, sandy banks and nearby open areas. They also nest in man-made banks. They are the principal bank-nesting swallows in western Washington.

Bank swallows are closely associated with sandy, vertical banks, even those created by human excavation. They adapt well to new surroundings and colonize areas quickly, necessary traits, since the banks in which they nest are often unstable and easily eroded.

Tips for Puget Sound Bluff Property Owners

For people wishing to maintain bird habitat on their property, things to include are:

- Multiple-acre patches of coniferous trees—good nesting areas for hawks and owls.
- Young stands of coniferous trees at various stages of growth—good hunting areas for Cooper's and sharp-shinned hawks.
- Quiet, protected areas away from human activity—good for all songbirds.
- Protected areas near water with big trees—good for all bird species.
- Tall snags (dead or dying trees over 10 feet)—good perch sites and nest sites for cavity nesting birds.
- Tall live trees—good nest and perch sites for several hawk species.
- Hedgerows and thickets bordering fields—good for songbirds and hawks.
- Large unmowed or infrequently mowed grassy areas away from bluffs—good for red-tailed hawks and other species that eat rodents and large insects such as grasshoppers.

References and Additional Information

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Nehls, Harry B. Familiar Birds of the Northwest: Covering Birds Commonly found in Oregon, Washington, Idaho, Northern California, and Western Canada. Portland, OR: Audubon Society of Portland, 1989.

Pendleton et.al., Raptor Management Techniques Manual. Institute for Wildlife Research and the National Wildlife Federation, Science and Research Series No.10, 1987.

Udvardy, Miklos D. F. Audubon Society Field Guide to North American Birds--Western Region. New

York: Alfred A. Knopf, 1977.

Internet Resources

American Bird Conservancy (Cats Indoors and other programs): www.abcbirds.org

Bald eagle protection rules. WAC 232-12-292 found at: http://www.leg.wa.gov/wac/index.cfm?fuseaction=Section&Section=232-12-292

Seattle Audubon's Birds of Washington State: www.birdweb.org/birdweb/

U.S. Forest Service Wildlife Species Life Form Information: www.fs.fed.us/database/feis/

Washington Gap Analysis: http://www.fish.washington.edu/naturemapping/wagap/public_html/

WDFW's Priority Species: http://wdfw.wa.gov/hab/phsvert.htm#birds.

AMPHIBIANS

The Puget Sound marine area bluffs support **tree-frogs, red-legged frogs, Western toads**, and several species of **salamanders**. Several of these, such as the western toad, are likely declining in portions of their range; however historical or baseline information is often incomplete for this species group. For detailed information on the above-mentioned species, see references below.

Tips for Puget Sound Bluff Property Owners

To provide safe spaces for amphibians on your property:

- Protect existing natural areas to the greatest extent possible. Protect woodlands, wetlands, stream corridors, shorelines, and other wildlife habitat; encourage your friends and neighbors to do the same. Support public acquisition of greenbelts, remnant forests, and other wild areas. Write to legislators and attend public meetings when regulations are being considered.
- Protect buffer areas next to streams, lakes, marine areas, and ponds. The vegetated buffers surrounding these areas protect the ecological functions and value of the breeding habitat, and provide needed upland habitat for amphibians.
- Wherever possible, protect migration paths between uplands and breeding sites. If amphibian migrations to breeding sites cross neighborhood roads, try placing signs to inform local drivers of this crossing. If a new road is to be constructed in migration areas, work for installation of amphibian crossing structures, such as small tunnels under the roadway. Amphibian movements can also be guided by means of drift fences and large logs. If you have an area on your property that is used by migrating amphibians, leave the area as natural as possible.
- Leave a portion of your grass unmowed, especially in areas that adjoin a wet area, forest edge, or any other distinct habitat, as well as any area that is being used by migrating amphibians. If you must mow in these areas, mow at slower speeds and be ready to step on the clutch or brake. Set the mower blades as high as possible, or use a weed-whacker and leave grass 6 inches high.
- Regularly mow any areas you want to keep as lawn to prevent longer grass developing where frogs may hide. Mowing in hot, dry weather will minimize the chances of finding amphibians, and making some disturbances before mowing may encourage frogs to hop out of the way. Don't mow or weed-whack when amphibians are seen during breeding migrations or juvenile dispersal periods.

Preserve leaf litter under trees and shrubs. Such material provides cover and moisture; it also attracts organisms that amphibians eat.

Retain stumps, logs, rootwads, rock piles, and other debris that provides a cool, moist habitat for amphibians. Such habitat features provide much needed cover. All these can be strategically located as "stepping stones" across exposed areas, or to bridge gaps between breeding ponds and woods. To be effective in exposed areas, keep the structures within 15 feet of each other.

With permission from landowners, you could salvage these materials from cleared or logged areas and install them in your landscape, preferably away from busy roads.

Avoid using pesticides and herbicides. Amphibians

6a. Attachment F

Soils and Biodiversity

Soils host a quarter of our planet's biodiversity.

Soil is one of nature's most complex ecosystems: it contains a myriad of organisms which interact and contribute to the global cycles that make all life possible.

Related links: http://www.fao.org/soils-2015/en/;
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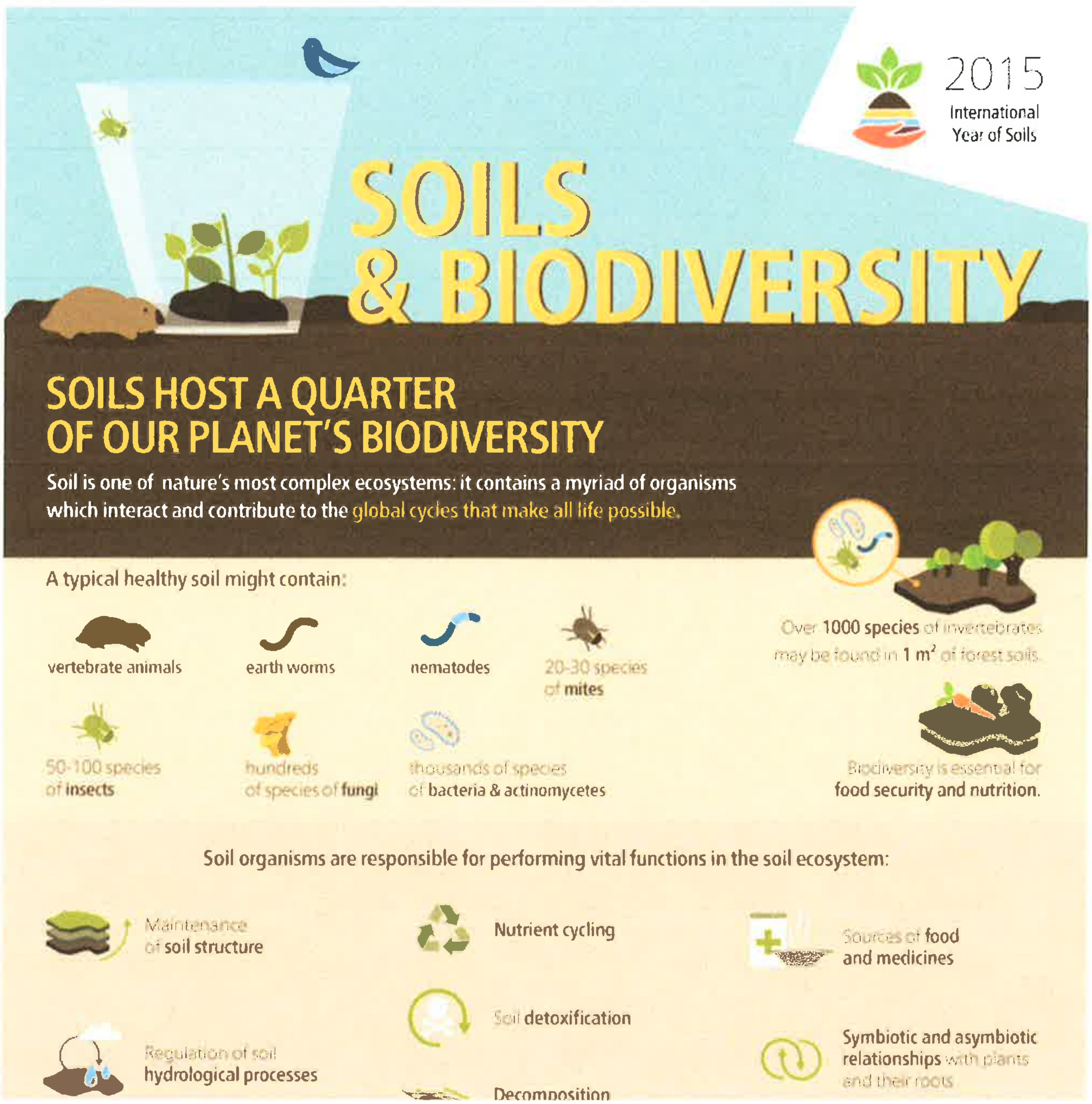


of organic matter

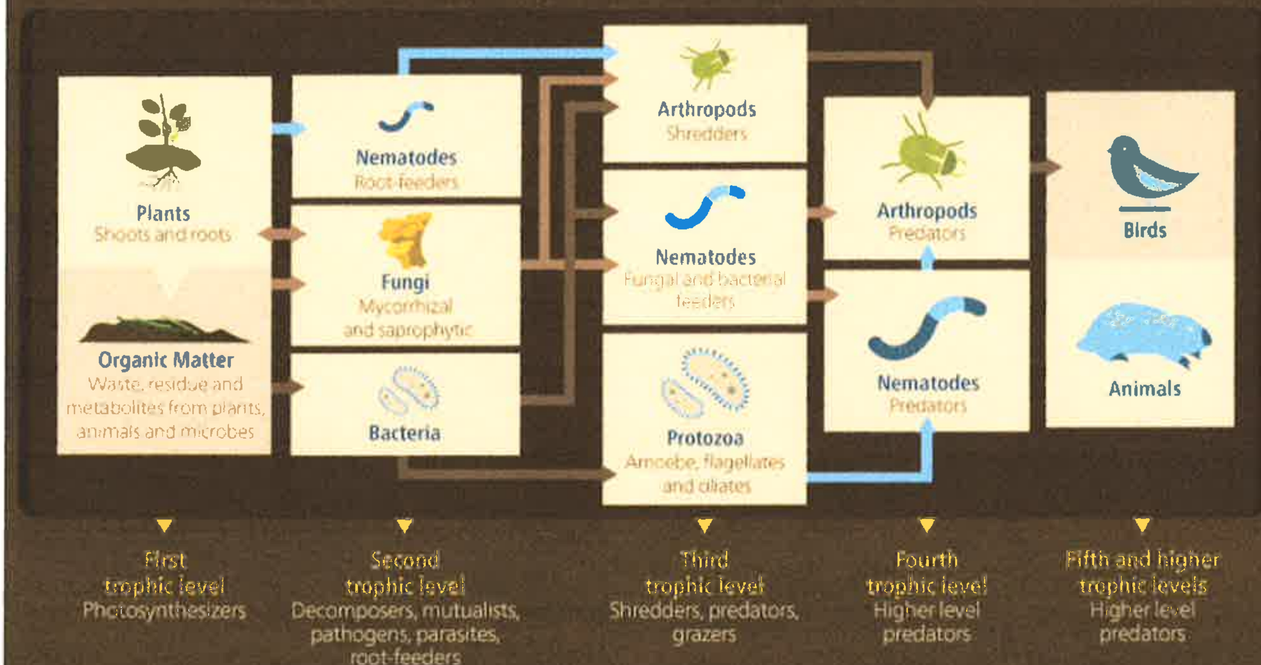
Gas exchanges and carbon sequestration

Suppression of pests, parasites and diseases

Plant growth control

THE SOIL FOOD WEB

When these diverse soil organisms interact with one another and with the plants and animals in the ecosystem, they form a complex web of ecological activity.



SOIL BIODIVERSITY AND AGRICULTURE

Clearing forested land or grassland for cultivation affects the soil environment and drastically **reduces the number and species of soil organisms.**

The overuse or misuse of agro-chemicals has resulted in environmental degradation, particularly of soil and water resources.

Agricultural systems and agro-ecological practices such as: agroecology, agroforestry, conservation agriculture, organic farming and zero-tillage can sustainably increase farm productivity without degrading the soil and water resources.

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